

# Combat Casualty Care and Surgical Progress

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The book of Revelation describes the 4 horsemen of the Apocalypse, conquest, death, famine, and war as the hardships that human kind must endure before the end of the world.<sup>1</sup> The hardships of war have been evident throughout history and are now illustrated for us at least twice a day on the morning and evening news. Not so obvious have been the benefits derived from surgical experience during war, or the benefits derived from the application of new knowledge and new technology to the treatment of combat casualties. These benefits have been most conspicuous in the realm of wound care, the recorded history of which begins by best estimate 3605 years ago.

The Edwin Smith (1600 B.C.) and the Ebers (1550 B.C.) papyri, which are 2 of Egypt's most important medical documents, both describe treatments for injured patients. The former describes 48 surgical cases, including the treatment of head wounds, and the latter recommends application of goat dung in fermenting yeast or a frog warmed in oil as topical therapies for burns and raw meat for crocodile bites.<sup>2</sup> The frog may represent the earliest example of the therapeutic use of biologic membranes.

Western surgery was simultaneously developing in Greece, as reported in the Homeric poems *The Iliad* and *The Odyssey*, composed in the 700s B.C., describing events that occurred 5 or 6 centuries earlier. *The Iliad* provides what some consider to be the first written description of the treatment of battle wounds. Specifically, Makaon, the son of Asklepios, removed an arrow from the side of Menelaus, the former husband of Helen over whom the Trojan War was fought, sucked out the blood, and applied a healing salve originally given to Asklepios by Cheiron, the centaur who had raised Asklepios and taught him the healing arts.<sup>3</sup> Menelaus' survival may be the first illustration of the importance of adequate debridement and the gentle handling of tissue. Such treatments were depicted on Greek pottery as in Figure 1 showing Achilles bandaging a wound on Patroclus, his cousin and best friend.

Three centuries later Hippocrates, 460–377 B.C., authored at least some of the 72 medical books collectively titled some years later, by order of the Pharaoh Ptolemaios Soter, *Corpus Hippocraticum*. His writings on surgery rec-

ommended using only wine to moisten a wound, giving little food and no drink but water for all injured patients including those with abdominal wounds, prohibition of walking, standing, and even sitting, and making pus form in the wound as soon as possible for the counterintuitive reason of reducing inflammation in the wound. Insertion of a tube in the chest wall for empyema drainage and the use of traction for fracture alignment are described. The oath attributed to Hippocrates is considered to be the earliest codification of medical ethics. Subsequent Hellenistic doctors beginning with Polybos, the son-in-law of Hippocrates and including Aristotle, adapted the classic Greek doctrine advanced by Empedocles that all materials were composed of the 4 elements fire, water, earth, and air to a system of medicine based on 4 elements (yellow bile, phlegm or mucous, black bile, and blood).<sup>4</sup> Since disease was considered to be caused by an imbalance of those elements, treatment consisted of attempts to restore balance by medical means with little if any role for surgery.

The shift of the center of medical progress to Rome over the next 4 centuries was accelerated by Galen, 130–200 A.D., who began his practice as physician to the gladiators in Pergamon, his birthplace. In 162, he moved to Rome, where his success in treating the wounds of gladiators attracted the attention of the emperor, Marcus Aurelius, who made Galen his personal physician. Galen was the author of some 400 works in which he describes removal of nasal polyps, removal of varicose veins, plastic surgery for cleft lip, uvulectomy for coughing, trepanning of the skull, and intestinal or abdominal wall suture of penetrating abdominal wounds of the gladiators. He is considered to have had an overall negative effect on surgical progress because of his advocacy of supuration as an essential and beneficial component of wound healing.<sup>4,5</sup> That is cited as being contrary to Hippocratic teachings, but the supposed difference may be the consequence of mistranslation of Hippocratic Greek into Galenic Latin. With regard to wound care, there was essentially no difference between the 2 because, as noted above, Hippocrates also insisted on treatment that promoted pus formation as soon as possible in wounds caused by weapons.

In the following years of the Middle Ages, surgical progress was modest at best because of the unquestioning acceptance of Galen's writings and the edicts of 2 ecclesiastical Councils. The Council of Clermont (1130), to preserve traditional monastic lifestyle, decreed that priests and monks should no longer practice medicine. Consequently, the monastic hospitals established in the fifth and sixth centuries were deactivated or taken over by lay physicians. Surgical progress was further impeded in 1163 when the Council of Tours issued the "Ecclesia Abhorret a Sanguine" ("the church

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**FIGURE 1.** The first written description of the treatment of battle wounds is attributed to the Iliad. Wound care was depicted on early Greek pottery such as this painting on a Greek vase found in Vulci in 1828 and dated 500 BC. Achilles is shown binding a wound on the left arm of his cousin and best friend Patroclus. The arrow resting parallel to the right leg of Patroclus has been placed there after removal from his arm. Reproduced by permission from the Bildarchiv Preussischer Kulturbesitz/Art Resource, New York.

abhors bloodshed”) edict.<sup>6</sup> This edict removed surgery from the practice of physicians, most of whom at that time were also clergymen, and in effect assigned an inferior status to surgical practice as compared with the practice of medicine, which further separated medicine and surgery.

Exposure to Arabic medicine, which occurred at the interface with the Byzantine Empire in the fifth and sixth centuries and increased during the 8 major crusades (1096–1270), also devalued surgical therapy. The Arabs used cautery for the treatment of bleeding wounds and ulcers, the obliteration of inguinal hernias, and the debulking of tumors. The use of cautery expanded greatly after the edict of 1163 since it did not violate the ecclesiastical prohibition of shedding blood. The Arab physicians did not abandon all surgery; and indeed, Rhazes, the most famous Arab physician of the ninth and tenth centuries, is credited with being the first to write about the use of animal gut for ligatures in operations and the use of warm, moist compresses on the exposed bowel during abdominal operations.<sup>7</sup>

Surgery was further restricted in 1215 when Pope Innocent III issued another *Ecclesia Abhorret a Sanguine*, which was intended to stop all surgical activity.<sup>4</sup> Fortunately, surgical progress was maintained by the efforts of the medical faculty at Bologna University. Hugo of Lucca and his son, Theoderic, who were keen observers and original thinkers, questioned a central tenet of Galenic wound care when they disputed the belief that wounds could properly heal only by

secondary intention after the formation of pus. In Theoderic’s book, *Chirurgia*, published in 1267, he advanced the then surgical heresy that it was not necessary for pus to form in wounds. He stated that there could be no greater mistake and considered pus formation to be against nature, to prolong illness, and to hinder healing and wound consolidation.<sup>4</sup> This concept, which preceded Pasteur by 6 centuries, was largely ignored and the theory of laudable pus persisted. Henri de Mondeville of France, who studied with Theoderic, became a strong proponent of pus-free healing. In the early 14th Century, he authored *Chirurgie*, the first surgical textbook of French origin. In the second volume of that work, he corroborated Theoderic’s position that wounds healed better and faster without suppuration. He proposed that foreign objects be removed immediately, that all bleeding be stopped, that the wound be closed and then dressed with compresses soaked in hot wine. He also described the benefits that accrued to those who practiced surgery conscientiously. “You need to fear neither fire, rain or storms. You do not have to take up religion, go on pilgrimages or anything of the sort, because you have saved your souls through your science. You can live without want and die in your homes; can live in peace and joy, glad that your pay will be plenty in Heaven.”<sup>4</sup> We can all accept such a generous assessment of our intrinsic merit.

Guy De Chauliac succeeded de Mondeville as the predominant figure in French surgery and furthered the rehabilitation of surgery and the restoration of the status of surgeons. In 1363, he authored a seven-part work entitled *La Grande Chirurgie* in which he described individualized wound care based on the characteristics of the wound, traction systems for the reduction and alignment of fractures, and the use of the “soporific sponge” as proposed by Theoderic for topical analgesia. In the third volume, he described 5 components of wound care; ie, the removal of foreign objects, the rejoining of severed tissues, maintenance of tissue continuity, preservation of organ substance, and prevention of complications. Even so, he remained a strong adherent of laudable pus, and as such eclipsed the work of Theoderic and de Mondeville. The long-term influence of *La Grande Chirurgie* has earned De Chauliac the perhaps undeserved reputation of having prevented progress in wound care for more than 5 centuries.<sup>6</sup>

German surgery made an early contribution to combat casualty care in 1497 when Hieronymus Brunschwig authored the first book to describe treatment of firearm wounds. In that volume, he promoted the doctrine originally proposed by Pfolspeundt that such wounds were poisoned by gunpowder.<sup>2</sup> That theory provided the rationale for cauterizing all war wounds and initiated a controversy that persisted for 300 years. Brunschwig is also credited with reporting the first surgical treatment of abdominal war wounds in 1525 when he described the repair of injured bowel.<sup>8</sup> Hans von Gersdorf, an Alsatian surgeon experienced in the wars of the time, published a field book of wound care in 1517 in which he advanced the care of the injured patient by recommending preoperative administration of opium and the use of an ox bladder as a pressure dressing to control bleeding in amputation wounds.<sup>2</sup>

During the next century, surgery was reestablished as the primary treatment of extremity war wounds, but cautery by application of heated irons to control bleeding in amputation wounds, or by pouring boiling oil into those wounds that did not require amputation, concluded the surgical procedures and preceded application of a dressing. In 1536, Ambroise Paré (1510–1590) changed the care of war wounds by improvising to overcome a logistic failure during the siege of Turin. When the supply of “seething” elder oil ran out, Paré, who claimed to have never seen, let alone treated, a war wound, applied what he called “a healing salve” made of yolk of eggs, oil of roses, and turpentine. The serene course of the patients treated with the “healing salve,” as compared with the severe signs and symptoms of inflammation in those treated with the seething oil, made Paré resolve “never so cruelly, to burne poor men wounded with gunshot.”<sup>9</sup> His classic treatise on shot wounds was published in 1545. Despite his revolutionary observation, Paré continued to believe that pus was necessary for optimum healing and searched for the “perfect” salve to stimulate suppuration. He ultimately obtained the secret recipe of a surgeon in Turin who was famous for his successful treatment of gunshot wounds. The perfect salve was prepared by adding earth worms steeped in Venetian turpentine and young pups just whelped to boiling oil of lilies.<sup>5</sup>

The 16th and 17th centuries were a time of consolidation during which the surgical repertoire slowly expanded and medicine became a science. Dissection provided detailed knowledge of anatomy as illustrated by Vesalius’ book *De Humani Corporis Fabrica Libri Septem* printed in 1543. In the latter half of the 16th Century, William Clowes was recognized as the greatest surgeon in Elizabethian England. In 1596, on the basis of his surgical training and experience in the British Navy, Clowes published a book for young surgeons in which he advocated debridement, extraction of foreign bodies, and avoidance of cautery in treating wounds.<sup>10</sup> Clowes contributed to the “gunpowder as poison” debate by stating that a shot wound was not necessarily poisoned, but the bullet could be smeared with poison before it was fired. This theory, which was readily accepted, is thought to have been responsible for the execution of many prisoners of war when the wounded compatriots of their captors died with infected wounds.<sup>4</sup>

Richard Wiseman (1625–1686), considered by many to be the father of English surgery, accepted the concept of gunpowder as a poison without such qualifications. Wiseman took part in the English civil war as a royalist, went into exile with Charles II, and was subsequently captured and put in the Tower of London when Charles’ attempt to return failed. He was given freedom to practice medicine at another prison but had to flee England when he became involved in another royalist plot. He served as a ship’s doctor in the Spanish fleet for 3 years; and when Charles was restored to the throne, his loyalty was rewarded by appointment as a doctor of the court. In his book entitled *Several Chirurgical Treatises*, Wiseman reintroduced cautery for wounds and, like Paré before him, recommended that gunshot wounds be bandaged with raw onions to counteract the effects of the gunpowder. Wiseman

also recommended that an onion-salt mixture be applied to burns before blistering occurred, but not after the blisters had ruptured lest one exaggerate pain and increase inflammation. In 1672, Wiseman performed one of the earliest vascular procedures, a two-stage removal of an aneurysm from an artery in the arm of a cooper.<sup>4</sup> Interest in diseases of the vessels was promoted by studies throughout the 17th Century that expanded knowledge of the circulation, especially the work of William Harvey published in 1628 and the discovery of the capillaries by Malpighi in 1661.

In 1620, when Plymouth Colony was established in Massachusetts, the treatment of war wounds was still in consonance with Galenic theory and the outlook for the injured soldier could only be considered bleak. Penetrating wounds were considered to heal best by secondary intention as a consequence of laudable pus and, if caused by firearms, to be poisoned. Burns caused by gunpowder or otherwise were treated by topical application of a thrice-boiled lotion of elder bark, *Sambucus Sempervive*, and moss from an old thatched house-top to which was added barrowes grease.<sup>11</sup> That ointment was applied to a piece of paper and placed on the burn. The effectiveness of that recipe, sent by Dr. Ed. Stafford to Governor Winthrop in 1643, is unrecorded. In addition to such wound care, “exhaustive treatment” was used to address the systemic consequences of injury and disease. This treatment, consisting of variable combinations and doses of bloodletting, sweating, emetics, laxatives, and enemata, which was applied to sick and wounded patients regardless of their injury or physiologic status, was later escalated to heroic dosage levels by Benjamin Rush. During the almost 4 centuries since that time, innumerable conflicts have occurred, and even though the intensity of battle and the severity of injuries have progressively increased, the surgical experience in earlier conflicts has progressively improved the care delivered to wounded and burned casualties in later wars and conflicts.

The American Revolution began with the battle of Lexington in April 1775. During the battle and the ensuing retreat, the British casualties consisted of 75 killed, 187 wounded, and 26 missing. The American casualties consisted of 51 killed, 40 wounded, and 5 missing. That favorable casualty ratio was markedly increased 2 months later at the Battle of Breeds (erroneously identified as Bunker) Hill, in which the British casualties numbered over a thousand (226 killed, and 828 wounded) and the American casualties numbered only 411 (140 killed and 271 wounded).<sup>12</sup> The casualty care was eclectic in respect to both providers and facilities. The injured were treated in both homes and public buildings by a wide variety of physicians, some of whom were found to be uneducated and unfit. In recognition of these problems, the second Continental Congress established the Hospital Department for the Army, which consisted of one Director General and Chief Physician, 4 surgeons, 1 apothecary, 20 mates, and various ancillary personnel. The Congress defined the duties of the Director General, which included provision of bedding, as well as medicines, and discussed how to access qualifications of surgeons.<sup>13</sup> Ultimately, committees of physicians were formed to evaluate surgeons, but their performance was

highly variable and regimental surgeons who were appointed by their friends and neighbors largely evaded the committees.

Before establishing the Hospital Department, the second Continental Congress had named George Washington Commander-in-Chief of the Continental Army. On October 16, 1775, the Continental Congress, thinking that the problem of medical leadership was being solved, elected Dr. John Morgan, "a conceited fool" in the words of James Boswell, the biographer of Samuel Johnson,<sup>15</sup> to succeed Benjamin Church as Director General of hospitals. Church had been convicted of treason and dismissed from the Army.<sup>14</sup> Morgan was said to be the leading physician in all of the colonies and to have founded the Medical College of Philadelphia, but he had also established an immutably adversarial relationship with Dr. William Shippen, who felt that he, not Morgan, deserved both of those honors. That personal hostility compromised the effectiveness of both men throughout the war. Morgan, in his attempts to centralize medical care and direct the treatment of serious injury to the general hospitals, antagonized the regimental surgeons who zealously guarded their prerogatives, particularly their right to requisition unlimited quantities of rum and wine. His attempts to control supplies, enforce hygiene, and demand professional competence won him few friends and only desultory support from the medical committee of the Continental Congress, which was chaired by Samuel Adams. Morgan labored heroically to provide care for the casualties of the Battle of Long Island and the Battle of Harlem Heights, but his efforts to obtain medicine and supplies were largely ineffective, at least in part because of the maneuvering of Shippen. When the Americans were driven from New York, Morgan opened a general hospital at Hackensack on the west side of the Hudson River. The immediate influx of more than 1000 sick and injured and shortages of medicine and other supplies compromised care.<sup>16</sup>

Morgan himself provided surgical care for the casualties at Hackensack by trepanning skulls and amputating injured limbs. The surgical armamentarium of the day, in addition to those 2 procedures, included removal of "easily reached" bullets and the "setting" of bones. John Jones, the founder of the Kings College Medical School in New York and its first professor of surgery, studied with the Hunters and brought their teachings back to colonial America. In 1775, Jones authored the first American surgical publication, a manual on the treatment of wounds and fractures for young military surgeons. The manual promulgated Hunterian practices as modified by Jones' experience as a volunteer surgeon in the French and Indian Wars. Removal of the bullet if easily reachable was emphasized and sutures were disdained, but if used were removed as soon as wound union was deemed complete, typically between 24 and 72 hours. Absence of swelling and lack of pus by the fourth day were considered to be bad signs indicating that wound "digestion," necessary for proper healing, was impaired. To avoid life-threatening infections, compound fractures were commonly amputated. Burns were treated by topical applications, which ranged from spirit of wine for superficial scalds to hog's lard for deep full-thickness burns. Bloodletting was a prominent feature in

the treatment of serious burns involving muscle and was supplemented with enemata and purgatives.<sup>17</sup>

The gunpowder as poison controversy was finally resolved in the latter half of the 18th Century by John Hunter (1728–1793), with whom Jones had studied. To hasten John's recovery from an acute attack of tuberculosis, his older brother William obtained an appointment for John as a doctor in the British Army. John survived the attack of tuberculosis and military campaigns in France and Portugal. In his last publication "Treatise on Blood, Inflammation and Gunshot Wounds," which was begun in 1763 and published in 1794, one year after his death, Hunter codified his experience with the treatment of war wounds. In that volume, he proposed the "novel" idea of treating gunshot wounds like other wounds, saying "This is ordinary surgery and it should also be war surgery in regard to shot injuries." Unfortunately, in that same volume, he said that a gunshot wound should not be made larger and "should not be opened simply because it is a wound."<sup>18</sup> This dictum, which limited wound exploration and debridement, almost ensured the appearance of laudable pus by the fourth day.

In mid-July 1776, Shippen had been elected by Congress to be surgeon of a small "flying camp" (a mobile tent or hut with a few beds and a surgeon's table) in New Jersey and was placed under Morgan's orders.<sup>16</sup> Shippen did not recognize that subordinate status, and by means of exaggerated reports of his successes and Morgan's limitations he succeeded in having Morgan relieved. Morgan demanded an official investigation and a Congressional committee ultimately gave him complete vindication. Morgan then collaborated with his friend Benjamin Rush to have Shippen court-martialed for "malpractice and misconduct in office." Some time later, in a letter to Morgan, Washington summarized the controversy, "I have understood that this clashing between Dr. Shippen and yourself was no small cause of the calamities that befell the sick in 1776."<sup>16</sup> When the College of Philadelphia was reconstituted as the University of Pennsylvania, the former medical school professors were all reelected. Shippen accepted his professorship, but Morgan requested that Shippen's professorship be withdrawn and, when it was not, refused to accept a professorship himself.

The personal antagonisms, the generally poor education of physicians and the limited resources available prevented development of a well-organized trauma care system and resulted in little improvement in wound care during our Revolutionary War. By virtue of clinical observation of what could be called accidental antisepsis, an improvement in wound care was identified by Dr. Charles Gilman. In caring for casualties from the Battle of Harlem, Dr. Gilman spilled rum on a badly infected hand and noted that the infection was quickly cured.<sup>18</sup>

The next war, that of 1812, was the conflict in which the British on August 24, 1814 sacked our capital and burned the White House in retaliation for our troops having burned the Canadian cities of York and Newark in 1813.<sup>19</sup> William Beaumont, then a regimental surgeon, described his work caring for casualties in the attack on York (Toronto) in the spring of 1813 as "wading in blood" to operate on 50 patients

with wounds "of the worst kind, I cut and slashed for 48 hours, without food or sleep . . ." <sup>15</sup> Shepard and Rich have recorded that in this war, as in previous conflicts, early amputation was practiced to shorten hospital stay and reduce the risk of infection, to reduce the trauma caused by transportation in horse-drawn vehicles and, when in retreat, to permit more rapid healing of the wounds of those patients who were left on the battlefield. <sup>20</sup> Incision of penetrating wounds to enhance drainage and removal of foreign bodies and fasciotomy to prevent tissue damage due to local swelling were used and brought the Hunterian dictum against enlarging wounds into question.

At the same time in Europe during the Napoleonic wars, the Baron Dominique Jean Larrey, "Napoleon's surgeon," improved the care of combat casualties by use of a light horse-drawn "flying ambulance" to effect rapid evacuation, which permitted immediate amputation of severely injured limbs on the battlefield. Larrey postulated that the shock of the injury rendered the wound relatively insensitive with corresponding reduction in stress when the operation was performed soon after injury. Larrey's system of battlefield care was put to the test in 1793 at the Battle of Metz and was so successful in saving patients and improving troop morale that Larrey was ordered to organize the medical care of all the 14 armies of the French Republic. <sup>21</sup> Larrey's operative speed and skill may also have reduced operative stress. He is credited with 200 amputations at the Battle of Borodino in 1812, or 1 every 7.2 minutes. Larrey could amputate at the hip joint in 15 seconds and perform a shoulder amputation in only 11 seconds. <sup>22</sup> Amazingly, Larrey and his assistants recorded a 75% recovery rate of patients upon whom they performed amputations. Larrey also reported the successful treatment of a transected ileum by exteriorization, the healing of sigmoid colon injuries without fecal fistula formation, and the successful treatment of lacerations of the bladder. <sup>23</sup>

In the mid-19th Century, the realization of pain-free surgery expanded the magnitude and duration of operative procedures that could be performed and increased the frequency with which surgery was undertaken by both surgeon and patient. Demonstration of the effectiveness of ether by Crawford Long in Danielsville, Georgia in 1842, and William Morton in Boston, Massachusetts in 1846, and demonstration of the effectiveness of chloroform by James Simpson in Edinburgh, Scotland beginning in 1847, set the stage for what some have termed an amputation mania in our Civil War. <sup>2</sup> Public acceptance of anesthesia was accelerated when Simpson administered chloroform to Queen Victoria for the birth of Prince Leopold in 1853. <sup>4</sup> The first use of anesthesia in military casualties occurred during the Mexican-American War. Dr. Edward H. Barton used ether to amputate a leg on March 29, 1847 and at least a dozen more times in the next 3 weeks to operate on wounded soldiers. Unfortunately, Army Surgeon John Porter considered anesthetic agents to be "universally injurious," and their use was terminated at the Army hospital in Vera Cruz. Chloroform was the preferred agent in both armies in our Civil War. H. H. McGuire, Medical Director of the Stonewall Brigade, reported that he and his staff used chloroform in more than 28,000 cases without a

death. <sup>24</sup> When McGuire removed a round ball from Jackson's right hand and amputated his left arm, chloroform was used as the anesthetic. <sup>25</sup>

Another advance in the care of combat casualties at the midpoint of the 19th Century was the improvement in hospitals and hospital services that occurred during the 1854 to 1856 Crimean War. The facilities and care provided the English soldiers at the start of that conflict were so bad that 18,000 of the original 25,000-man force died of diseases such as cholera, dysentery, and scurvy within a year. The British Sanitary Commission, appointed by Queen Victoria, markedly upgraded both hospitals and general living conditions. Florence Nightingale and her cadre of 37 nurses coordinated medical relief activities, emphasizing sanitation and hygiene in the hospitals. The striking reduction of death from disease established new standards for military hospitals and made Nightingale a true heroine. <sup>26</sup>

The first battle of Manassas (known as Bull Run by the Union Army) epitomized the state of surgical care for the wounded at the start of what was known in the South as the War of Northern Aggression. In that battle of July 21, 1861, casualties for the Union Army totaled 481 killed, 1011 wounded, and 1460 missing, while casualties for the Confederate Army totaled 387 killed, 1582 wounded, and 13 missing. <sup>26</sup> There were no field hospitals other than commandeered churches, commercial buildings, or houses. In addition to that, equipment and supplies were scarce, physicians were inexperienced or even worse incompetent, conditions in the treatment facilities were unsanitary, and there was no plan or capability to evacuate the patients in an orderly manner. Consequently, many injured lay on the battlefield for days without food, fluid, or medical care.

The Sanitary Commission, founded by Henry W. Bellows and patterned after the British Sanitary Commission, was established by Lincoln's executive order of June 13, 1861. The Commission sent its recently hired executive secretary, Frederick Olmsted, to Washington to survey the capabilities of the medical department and review the medical and surgical care, or lack thereof, during and after the Manassas engagement. Olmsted's report to the Commission, which detailed the myriad of problems of the Union Medical Department, galvanized it into action. Under the leadership of Olmsted, the Commission played a major role in the construction of hospitals, development of a transportation system for casualties, organization of the ambulance service, examination and evaluation of physicians, a program of camp and hospital inspections, and provision of medical and hospital supplies and equipment. C. A. Finley, the Surgeon General when the Commission was established, viewed it with antipathy and resisted all innovation. Olmsted and the Commission facilitated Finley's retirement and successfully lobbied to have William Hammond appointed Surgeon General in April 1862.

Hammond promptly addressed the concerns of the Sanitary Commission. The Union Army General Orders No. 147 dated August 2, 1862 authorized the formation of an ambulance corps of the Army of the Potomac. Dr. Jonathan Letterman developed a system, ultimately used by all Union

Armies, in which each regiment was supported by 3 ambulances each with 2 privates and a driver and one transport cart with a driver. Unfortunately, this transport system, which filled a previous void, was of limited capacity and frequently overwhelmed by the number of casualties needing transport.<sup>27</sup> Hospital construction proceeded so rapidly that 84,000 beds were available for the sick and injured in 182 facilities by June 1863. That number increased by nearly 40,000 over the subsequent year. Because the size of the hospital facilities made it difficult to locate patients, Olmsted requested and received funding to develop a hospital directory, which by June 1863 covered all the general hospitals in the Army and ultimately listed more than 215,000 soldiers.<sup>27</sup>

Hammond also established the United States Army Medical Museum, to which an ultimate total of 1349 operative specimens from injured soldiers were sent and made available for review and study.<sup>26</sup> He also drew up plans for a graduate medical school but could not obtain support from Secretary of War Stanton for that project. Under Hammond's leadership and by order of Congress the Medical Department was reorganized in 1862 to increase centralization and improve delivery of medical care. In late 1862 after the Peninsula campaign during which he had served as General McClellan's Medical Director, Jonathan Letterman extended the medical reorganization to the regimental level. Letterman also reorganized the medical supply system to minimize waste and enhance patient care by placing one physician from each regiment at a dressing station near the front to provide first-aid and located the other physicians at the division's field hospital. One medical officer was delegated to keep records of every admission, one was delegated to provide shelter, bedding, fuel, and water, and organize the kitchen, and other physicians were assigned as wound dressers. In a revolutionary move, Letterman decreed that only the 3 physicians in each division with the most extensive surgical experience would be permitted to perform surgical operations. That policy, which made specialized skills and documented experience requisites for recognition of proficiency and professional privileging, was unprecedented. The necessity of demonstrating surgical expertise to receive the title of "Operating Surgeon" has recently been identified by the surgical historian Ira Rutkow "as one of the most momentous medical reforms to come out of the Civil War."<sup>26</sup>

Advances in the care of combat casualties that occurred in the Civil War included the widespread use of general anesthesia (Fig. 2), delay of primary amputation to reduce the effect of "wound shock," demonstration of the effectiveness of bromine in the treatment of hospital gangrene, the use of pavilion-type hospitals, the organization of an ambulance service, and the institution of competence-based physician credentialing. Like Letterman, J. J. Chisholm, the Chairman of Surgery at the Medical College of the State of South Carolina, who received the first medical appointment for active military service issued by the Confederacy, recommended that surgeons be examined by senior surgeons before they were allowed to perform amputations. Dr. Chisholm published a manual of military surgery in July 1861 in which he denigrated the concept of laudable pus, disparaged heroic

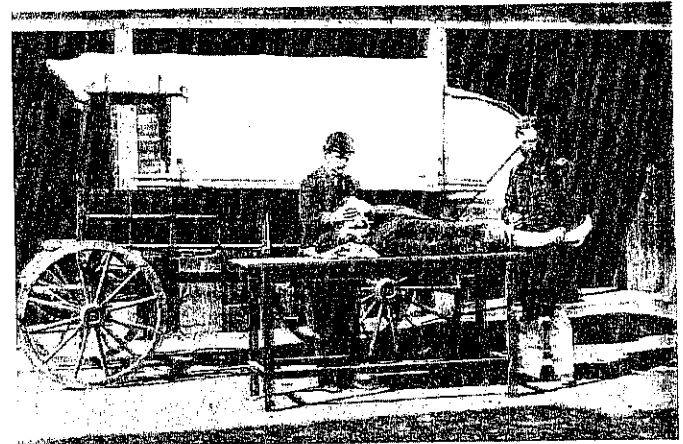


FIGURE 2. A horse-drawn Autenrieth Medicine Wagon used by the Union Army stands behind an operating table upon which a patient is being readied for surgery. The surgeon is examining the leg to be amputated and his assistant is using a cloth cone to administer the anesthetic. Courtesy of the National Museum of Health and Medicine, Washington, DC.

therapy, and emphasized the importance of nutrition and nursing care.<sup>28</sup> There were also 2 instances reported in which Union Army surgeons infused unmatched whole blood because of "failure to rally" after amputation of a gangrenous leg. Both patients were said to have had a favorable systemic response and no complications, but 1 patient died 12 days later with diffuse uncontrollable bleeding from the amputation stump. The other patient recovered, received a prosthesis, and died 3 years later as a pensioner.<sup>29</sup>

Additionally, surgeons in the Confederate Medical Department confirmed the benefits of primary amputation. In Richmond hospitals in the summer of 1862, only 82 (30%) of the 272 patients undergoing primary amputation expired, but 163 (53%) of the 308 patients undergoing secondary amputations did so. In the first 3 years of the war, surgeons of the Confederate States Medical Department recorded only 315 deaths (28%) in the 1142 patients undergoing primary amputation, and 284 deaths (52%) in the 546 cases of secondary amputation.<sup>30</sup> Partial or total excision of injured joints was carried out by surgeons in both armies. The claims of spontaneous restoration of function are somewhat dubious, but function may have been partially restored by the braces or artificial limbs provided in the North by Augustus Marks of New York City or by B. Franklin Palmer of Philadelphia, who claimed to have issued 7000 artificial limbs to Civil War amputees.<sup>26,31</sup>

Each Surgeon General, Hammond of the Union forces and Samuel Preston Moore of the Confederate forces, claimed to have originated pavilion-type hospitals. Similarly, a physician from each Medical Department, Dr. N. R. Smith of the Confederate Medical Department and Dr. John T. Hodgen of the Union Army Medical Department, designed a splint for extension of a fractured limb.<sup>30,32</sup> Each medical department also established specialty hospitals, e.g., orthopedic and hernia hospitals by the Confederate Medical Department and hospitals for smallpox patients, eye and ear patients,



and patients with diseases of the nervous system by the Union Medical Department. In the latter hospital in Philadelphia, William Keen and S. Weir Mitchell conducted studies of the neurologic effects of wounds and mental stress, the results of which were published as a monograph in 1864 entitled "Gunshot Wounds and Other Injuries of Nerves."<sup>26</sup>

The limitations of Civil War wound care included infection, which was virtually universal and still considered desirable, secondary hemorrhage, and the withholding of operations for patients with abdominal wounds, chest wounds, and pelvic fractures. The reuse of clothing, bedding, and even dressings, failure to cleanse hands or instruments, lack of general sanitation, and the misuse of antiseptic agents resulted in a prohibitively high infection rate. Carbolic acid and sodium hypochlorite, although available, were used to treat gangrene, not prevent it. Common forms of infection included erysipelas, with a mortality rate of 8%, and hospital gangrene, which if untreated had a mortality rate between 38% and 62%, but only a 2.6% mortality rate when treated with topical bromine.<sup>26</sup> Tetanus, although relatively infrequent, had a mortality rate of 89% and pyemia, the most dreaded form of infection, was associated with a mortality rate of 97%. Pyemia was the cause of 6% of deaths from wounds even though it occurred in only 1% of wounded patients.<sup>32</sup>

Bleeding was classified according to the time of occurrence. Bleeding within 24 hours was rare and considered to be primary. Secondary hemorrhage, which occurred later, was commonly related to the sloughing of ligated arteries and was associated with a 62% mortality.<sup>32</sup> The ligatures that were used to control arterial bleeding were typically left long enough to protrude from the wound and were gently "tugged" each day until they came free of the wound, accompanied by often fatal secondary hemorrhage if that vessel was not occluded by organized clot or healed.

Penetrating abdominal wounds, typically not operated upon, had an overall mortality of 87%, which ranged from 59% with colon involvement to 100% with small bowel involvement. Surgical intervention was also uncommon in the treatment of chest wounds, which, if caused by a cutting weapon, were associated with a 9% mortality, but if caused by gunshot, as occurred in 8700 patients, were associated with a mortality of 62%. Pelvic fractures, which were commonly complicated by osteomyelitis, impaired mobility, and intractable pain, produced an 80% mortality.<sup>32</sup>

Basic science research findings contributed to a third 19th Century advance in combat casualty care which occurred too late to be applied in the Civil War. Beginning in 1861 with his identification of bacteria as a cause of putrefaction, Louis Pasteur focused his work on the effects of microorganisms on biologic processes. He developed vaccines for both human and animal infections, described the toxic effects of various bacteria, and discovered *Streptococci* and *Staphylococci*. Building on Pasteur's findings, Joseph Lister developed a method of antiseptics using a carbolic acid spray during operative procedures. His technique, first reported in 1867, reduced the death rate after amputation from 16 of 35 cases (46%) to 6 of 40 cases (15%). Antiseptics was

viewed with skepticism and only slowly accepted in the United States. The general adoption of antiseptics was accelerated in 1877 when Robert Koch, Professor of Hygiene and Bacteriology in Berlin, published a paper confirming that bacteria caused wound infections. By the turn of the century, the success of antiseptics had led to the development and implementation of asepsis, including sterilization of equipment and supplies and the use of sterile operating garb, sterile drapes, and rubber gloves. The use of surgical masks was adopted in the early years of the 20th Century.<sup>33</sup>

The Spanish-American War, which lasted 5 months in 1898, was the first conflict in which the benefits of Lister's discovery were realized on the battlefield. Antiseptic treatment of wounds began at the time of wounding by application of the antiseptic dressing carried in the first-aid package fastened to each soldier's cartridge belt. Occlusive antiseptic dressings were applied to virtually all wounds of the extremities, chest, and abdomen. It was reported that several patients with penetrating abdominal wounds treated only with antiseptic occlusive dressings survived. Many surgeons before Lister had used a variety of antiseptic agents in the treatment of wounds and wound infections. The word antiseptic is credited to John Pringle, a British Army surgeon, who in 1750 used it to describe the action of strong acids in preventing putrefaction of tissue in dead animals.<sup>34</sup> As noted above, Hippocrates and Gilman used wine and rum, respectively, to dress wounds, and the Union Army surgeon Middleton Goldsmith used bromine to treat hospital gangrene. In their paper on pre-Listerian, antiseptic management of compound fractures, the Wangensteens noted that, by the late 18th Century, various alcohol solutions, chlorine, hypochlorite, and silver nitrate had all been used in the treatment of patients with compound fractures. The English surgeon John Crowther, in the early 19th Century, treated 28 consecutive open fracture patients with hemp dressings dipped in liquid wood tar and all survived. The Baron Larrey reported the successful treatment of 12 compound fracture patients with topical application of styrax, a benzoin compound, and Edward Bennion, a Welch surgeon, who never published, was reported by colleagues to successfully treat open fractures with lint soaked in compound tincture of benzoin.<sup>34</sup> Early adequate debridement made possible by anesthesia and the use of effective antiseptic dressings reduced the need for primary amputation in casualties with open fractures.

The 3681 deaths from disease in the Spanish-American War far exceeded the 293 deaths due to wounds.<sup>35</sup> That 12:1 ratio reversed the progressive decrease in the disease-death to battle wound-death ratio that had gone from 9:1 in the American Revolution to 8:1 for the British forces in the Napoleonic Wars, to 7:1 for American forces in the Mexican-American War, to 3:1 for allied forces in the Crimean War, to only 2:1 in the Civil War. Conditions in which the troops lived were such that the overall health of the Army in the Civil War was considered good when as many as one fifth of personnel were too sick to be effective.<sup>36</sup> The reduction in the death rate from wounds in this conflict was attributed to the first aid packet which facilitated prompt institution of "antiseptic occlusion" as treatment of virtually all wounds.<sup>35</sup>

At the 1898 meeting of the Southern Surgical Association, the advisability of laparotomy for casualties with penetrating abdominal wounds was prominently discussed. Dr. W. E. Parker of New Orleans, who had served as a consulting surgeon in Cuba, noted that even though he favored laparotomy in civilian life "when I saw the conditions, I strongly advised against laparotomy." He based that recommendation upon the small caliber of the bullets, the lack of hot water, the absence of trained assistants, and concern that the time required for laparotomy would compromise the care of the other casualties. Floyd McRae of Atlanta and Horace Grant of Louisville disputed that position; Grant stated "the first thing to be done is to transport the patient to a convenient place and a skilled hand should do a laparotomy."<sup>37</sup> Operation for patients with penetrating abdominal wounds was not generally accepted, even in civilian life, in the first decade of the 20th Century. At the 1907 meeting of this Association, La Grand Guerry of Columbia, South Carolina presented a paper, which he said he submitted "because of the requirement of the Council that each member had to write a paper once every 3 years." Dr. Guerry recommended operation as soon as possible, administration of a pint of normal saline, routine use of a midline incision, copious saline irrigation of the peritoneal cavity, maintenance of the Fowler position after surgery, and postoperative administration of saline by enemata. The discussions of that paper indicated that many surgeons still did not consider immediate laparotomy for penetrating abdominal wounds to be the standard of care.<sup>37</sup>

At the beginning of World War I (WWI), the laparotomy controversy persisted, as evident in an invited presentation by a guest at our 1914 meeting. That guest, Dr. Charles Richard, a Colonel in the Medical Corps of the U.S. Army, pointed out that there were numerous patients in whom perforation of the abdominal viscera had occurred who survived without operation, while operations on such patients "had been attended by a very high mortality."<sup>37</sup> That report, like others supporting nonoperative management, provided little or no information about how many patients died when they were treated nonoperatively. In the Wars of the German Order in the latter half of the 15th Century, von Pfolseundt, who originated the doctrine of poisoned gunshot wounds, repaired wounded bowel by transection and insertion of a silver tube over which the ends of the bowel were tied.<sup>2</sup> Operative repair of abdominal wounds, first reported by Brunschwig in 1535, had been practiced to a very limited extent thereafter.<sup>8</sup> In 1798, as noted above, Larrey repaired a transected ileum. Thereafter, Bauden who advocated finger exploration of penetrating wounds to identify blood, feces, or gas, performed 2 enterorrhaphies with one survivor in the French-Algerian War (1830).<sup>8</sup> Laparotomy was essentially forgotten during our Civil War and, when practiced in the Spanish-American War, again to a limited extent, it was reported to be associated with universal fatality in both the American and the Spanish hospitals in Cuba.<sup>35</sup> In the 1880s, James Marion Sims, on the basis of his experience in the Franco-Prussian War (1870–1871) was a strong advocate for surgical treatment of penetrating abdominal gunshot wounds.<sup>38</sup> In the first years of the Boer War (1899–1902), British

surgeons performed laparotomies on 26 patients with penetrating abdominal wounds and 18, or 69%, died. That experience supported nonoperative management as the standard of care for abdominal war wounds until WWI.<sup>8</sup>

Shortly before WWI, an extensive favorable experience with laparotomy for penetrating abdominal wounds was reported from Russia. Viera Gedroitz, a Russian princess who had been expelled from finishing school because of revolutionary activities, completed medical school, obtained surgical training and qualifications in Germany, became physician to the Imperial household and ultimately Professor of Surgery of the University of Kiev. During the Russo-Japanese War of 1904 to 1905, Dr. Gedroitz outfitted a railway car as an operating room in which she performed laparotomies on 183 patients with penetrating abdominal wounds. She achieved such good results that the Russian Army adopted the procedure. The good results were considered at least in part to be attributable to her strict enforcement of a policy of operating only on patients for whom the interval from time of injury was 3 hours or less.<sup>8,38</sup>

In the early years of WWI, the British surgeon Cuthbert Wallace considered the failures of operative treatment to be due to delay of surgical intervention, and he and Owen Richards championed the operative management of casualties with penetrating abdominal wounds.<sup>39</sup> From 1915 onward, laparotomy became the standard of care, but mortality remained high, 53% in 3520 abdominal operations performed by British surgeons from July 1915 to September 1917 and 66% in abdominal casualties reported by the surgeons of the American Expeditionary Force (Table 1). The persistent high mortality, attributed to delay from injury to operation which often exceeded 10 hours and to inadequate resuscitation,<sup>8</sup> delayed acceptance of operative intervention as the standard of care.

Beginning in 1915, prior to the U.S. entry into WWI, Western Reserve University Medical School, Harvard Medical School, and the University of Pennsylvania Medical School successively sent units to staff a military hospital and motor ambulance service in Neuilly-Sur-Seine and provide casualty care. Harvey Cushing, with the Harvard unit, recorded delayed transport of casualties and the breakdown of operating room conditions and general sanitation, information that he used in preparing for his return to France in 1917. After 6 weeks, Cushing returned to the United States, where he recruited personnel and attempted to establish a base hospital on the Boston Common to involve the public in the war effort. That project met with intractable and highly vocal resistance.<sup>40</sup> Even so, those activities enabled Cushing to rapidly organize Base Hospital 5 when U.S. forces were mobilized and begin operations in France in May 1917. Shortly thereafter, Cushing reported that the Base Hospital had seen 499 patients and evacuated 4 patients a minute during one 27-hour period. He noted that as the trenches increased in depth from 1915 to 1917, head wounds became more common and blindness an increasing problem.<sup>40</sup> Cushing is said to have operated upon thousands of men and to have kept extensive records on all. He assiduously removed



TABLE 1. Hospital Mortality of Combat Casualties (1898–1973)

Conflict	All Wounds Admitted	Abdominal Wounds					Injury to Admission Interval in Hours <sup>90</sup>	Total Number Who Served <sup>93</sup>	Deaths <sup>93</sup>
		All	Visceral Injury <sup>91</sup>						
			Colon	Jejunum and Ileum	Duodenum	Liver			
Spanish-American War		65%* <sup>44</sup> –100%† <sup>39</sup>						306,760	2446
World War I									
British		60% <sup>8</sup>							
U.S.	8.5% <sup>44</sup>	45% <sup>43</sup> –66% <sup>8</sup>	77%	75%	80%	67%	12–18	4,734,991	11,516
World War II									
British		42% <sup>8</sup>	54%	48%		41%			
U.S.	3.3% <sup>53</sup>	15% <sup>53</sup> –24% <sup>8</sup>	37%	30%	57%	27%	10.4	16,112,566	405,399
Korea	2.5% <sup>92</sup>	8.85% <sup>63</sup>					4–6	5,720,000	36,568
Vietnam	2.3% <sup>63</sup>	9% <sup>63</sup>					1.2–5	8,744,000	58,203
*Nonoperative treatment. †Operative treatment.									

\*Nonoperative treatment.

†Operative treatment.

all intracranial foreign bodies and developed a magnet to retrieve metallic fragments from the brain.<sup>41</sup>

Cushing also established professional relationships with Sir Almroth Wright and Alexis Carrel. Wright developed an effective vaccination against typhoid, which had caused such devastation in the Spanish-American War. Wright insisted upon the closure of clean wounds to permit phagocytes to sterilize them and recommended continuous irrigation of only dirty wounds to stimulate the leukocytes in those wounds. That position placed Wright in opposition to Alexis Carrel, who had developed a system for the antiseptic treatment of war wounds.<sup>40</sup> Carrel, in collaboration with the English chemist Henry Dakin, designed an 0.5% solution of sodium hypochlorite and dichloramineT, which was infused every 2 hours through catheters placed in the depths of the wounds.<sup>42</sup> Many surgeons visited Carrel's hospital at Campiègne to observe and learn the Carrel-Dehelly-Depage technique of wound care, which was reported to both prevent and treat infections and significantly reduce the rate of amputation.<sup>43,44</sup>

At the 1917 meeting of this Association, interest in the war was indexed by the 10 trauma papers that were presented. The papers accurately reflected surgical theory and practice of the day. The author of one paper concluded that shock was a "disordered condition of the higher nerve centers." The essayist considered the hemodynamic signs of shock to be caused by blood being "locked up principally in the splanchnic area," which would make infusion of fluid only transiently effective.<sup>37</sup> Dr. J. M. T. Finney, the President of the Southern Surgical Association in 1912, had been given the rank of Brigadier General and appointed Chief Consultant in Surgery for the American Expeditionary Forces. To address the problem of shock, General Finney established a Central Laboratory for the AEF under the direction of Major George W. Crile where laboratory determinations could be carried out in support of the clinical studies of casualties. He also placed Walter B. Cannon in charge of an experimental surgery department at the Central Laboratory.<sup>35</sup> In that facility, correlative animal studies were conducted. The results of the

shock studies were quickly applied to improve the resuscitation of the wounded.

Shortly after the Spanish-American War, another basic science discovery led to an improvement in the care of combat casualties in WWI. In 1901, Karl Landsteiner described the A, B, and O blood groups and in the following year, Sturli and De Castello described the fourth, or AB, blood group.<sup>45</sup> The subsequent development of in vitro testing for compatibility reduced the risk of complications and expanded the use of blood transfusions. Unfortunately, cumbersome transfusion apparatus, coagulation during infusion, and several conflicting systems of blood group classification limited the clinical usage of blood transfusion. Dr. O. H. Robertson, who had worked in Peyton Rous' laboratory where he conducted studies on anemia, enlisted in the Harvard Unit organized by Harvey Cushing and traveled with that group to France in May 1917. At Base Hospital 5, Robertson focused his activities on the problems of blood transfusion. He quickly developed an apparatus for transfusing blood and by late 1917 had carried out transfusions with preserved "universal donor" (Moss classification group 4) blood. Over the next year, Robertson conducted clinical studies in the Resuscitation Ward of Casualty Clearing Station 48 and other Casualty Clearing Stations, where he administered blood transfusions to casualties and recorded their beneficial responses. Those results caught the attention of the surgeons in the British Expeditionary Force, who requested Robertson to train transfusion teams and develop transfusion equipment for them. Robertson returned to the United States in January 1919 having established blood transfusion as a feasible, safe, and effective component of combat casualty care.<sup>46</sup>

The discovery of x-rays by Wilhelm C. Roentgen in 1895 was quickly followed by the development of x-ray equipment used by the military. Improved equipment including fluoroscopic screens facilitated the radiologic localization of foreign bodies and enhanced wound debridement in casualties during WWI.<sup>35,40</sup> The use of antitetanus serum improved casualty care in WWI by essentially eliminating

tetanus as a complication of war wounds. Although transportation could be delayed for hours by the weather or the tactical situation, casualties generally benefitted from more rapid transportation by motorized ambulance to definitive treatment facilities where for the first time in warfare surgical care could be provided by surgical specialists. During WWI, the Americans sustained 326,000 total casualties, 180,000 battle casualties, and 53,000 dead, for the French 1.7 million dead, for the British 660,000 dead of 3.5 million casualties, and for the Germans 1.6 million killed.<sup>40</sup> Those numbers almost obscure the fact that the reduced number of wounded who died represented an improvement over prior conflicts.

Between the 2 World Wars, agents to control and eliminate microorganisms were discovered and developed. Gerhard Domagk, who received a Nobel Prize in 1939, studied the effects of aniline dyes on bacteria and developed Prontosil, which was patented in 1932 as the first of a family of sulfonamides.<sup>47</sup> The toxicity of the "sulfa" drugs stimulated the search for other antibacterial agents. In 1929, Alexander Fleming discovered penicillin, the first effective antibiotic. Unfortunately, the clinical potential of penicillin was not realized until the opening years of World War II (WWII), and even then large scale production was slow in developing.<sup>48</sup> Surgeons of that day reported distilling and recrystallizing penicillin from the urine of patients who were receiving that drug and then recycling that "second hand penicillin." Since that time, a veritable explosion of antibiotics has occurred, and at present, a specific antibiotic or antibiotic combination can be selected to prevent or treat infection caused by virtually any microorganism. To define the role of the newly discovered antibiotics in the treatment of war wounds, the U.S. Army Surgical Research Unit was established at Halloran Army Hospital on Staten Island in 1943.<sup>49</sup> Colonel Edwin J. Pulaski, who had spent a year studying surgical infections with Dr. Frank Meleney at Columbia University, was the first commander of that Unit, which has made major contributions to burn and trauma care for combat casualties over the past 6 decades.

In WWII, the care of the wounded was further improved by a reliable supply of blood products and type-specific blood, the use of antibiotics, and the development of an Army Medical Corps trauma system providing continuity of care from the field trauma center to the rehabilitation hospital including during transport over long distances by vehicle, train, ship, or aircraft. The care provided by well-trained surgeons was another factor that improved survival of those injured in combat. Auxiliary surgical groups were used to overcome the relative shortage of highly qualified surgeons. The surgeons in those groups were deployed as mobile teams to augment the surgical capability of any treatment facility, from a field hospital supporting a division clearing station to a general hospital. The surgeons in the 5 auxiliary groups formed under the command of Col. James C. Forsee were highly trained specialists designated by the Surgical Consultants Division and included anesthesiologists in addition to surgeons representing all the surgical specialties. The members of those groups maintained detailed case records, which were invaluable in documenting improved outcomes

and developing "evidence-based" policies for the management of casualties.<sup>50</sup>

The tradition of integrated clinical and laboratory research within the Army, which began with the studies of William Beaumont in 1822 and continued with Wier Mitchell and Keen studying neurologic wounds, Walter Reed's studies of Yellow Fever, and the Central Laboratory in WWI, was maintained during WWII by the actions of Edward D. Churchill, a member of the Southern Surgical Association. Colonel Churchill organized the Board for the Study of the Severely Wounded, which was established in September 1944. During the 9 months of its existence, the physicians of the board, which included surgeons, anesthesiologists, and pathologists, conducted studies of the crush syndrome, the general pathology of traumatic shock, and the physiologic response to injury. In the 9 patients with crush injury, those investigators found that the administration of sodium bicarbonate or the infusion of hypertonic dextrose solutions produced no beneficial effects and all of the 5 patients who died showed histologic evidence of lower nephron nephrosis. In one patient with a severe transfusion reaction, a 10% solution of sodium chloride was infused, but no effect on urinary output was observed. The Board reported that the occurrence of lower nephron nephrosis increased markedly in patients with severe shock as compared with patients with mild or moderate shock. When considering the occurrence of pulmonary edema in casualties with shock, the Board raised the possibility that "it could be brought about or at least intensified by over-enthusiastic intravenous fluid therapy," a concern that antedated Da Nang lung by 25 years.<sup>51</sup> Lyman Brewer and the other surgeons on the thoracic surgery team of the Second Auxiliary Surgical Group described what they termed the "Wet Lung in War Casualties" and considered it to be a previously undescribed form of pulmonary edema.<sup>52</sup>

Fred W. Rankin of Lexington, Kentucky, who had served as President of this organization in 1937, became Brigadier General Rankin and Director of the Surgery Division of the U.S. Army Medical Department in WWII. In 1949, Dr. Rankin reported to the American Surgical Association that combat casualty care had markedly improved during that conflict and noted that the mortality of casualties with penetrating abdominal wounds had decreased to 15%, one third the mortality observed in WWI.<sup>53</sup> The mortality of patients with penetrating abdominal wounds decreased from 66% in WWI to 24% in WWII and was almost one half the 42% mortality of similar British casualties (Table 1). That lesser mortality rate compared with the British rate was attributed by Claude Welch to the greater proximity of definitive surgical intervention made possible by the attachment of mobile surgical teams to division level field hospitals of the U.S. Army.<sup>8</sup> The hospital mortality rates associated with injury of specific intra-abdominal organs (Table 1) as reported by the second Auxiliary Surgical Group established benchmarks of the day, which were markedly less than those of WWI. The reduction of those rates to levels much below those of British surgeons confirmed the importance of reducing the injury to surgery interval. Brewer et al reported even more striking reduction in the mortality of patients with

penetrating chest wounds, which had been associated with a 62% mortality in the Civil War and a 25% mortality in WWI, to only 10%.<sup>52</sup>

Two directives issued in 1943 by Major General Norman Kirk, Surgeon General of the Army, contributed to that increased survival and influenced the surgical care of combat casualties for several decades. In April 1943, a directive stated that "The guillotine or open-circular method of amputation is the procedure of choice in traumatic surgery under war conditions. Primary suture of all wounds of extremities under war conditions is never to be done."<sup>54</sup> Over 20 years later, Owen Wangenstein supported that policy when he wrote, "All military experience indicates a superiority of delayed closure of contaminated wounds."<sup>54</sup> On October 23rd of that year, Kirk issued Circular Letter No. 178 stating, "in large-bowel injuries the damaged segment will be exteriorized by drawing it out through a separate incision, preferably in the flank."<sup>55</sup> Those practices persisted in postwar surgery and were indirectly praised by Edward D. Churchill in 1953 when he said, "Patients in civilian disasters fare better when treated by the techniques of experienced war surgeons."<sup>54</sup> Although current civilian practice favors primary closure of amputation wounds and primary closure of colon wounds, recent reports of complications in patients treated in Iraq with immediate repair of colon wounds support reassessment of the management of colon injuries in wartime casualties. When surgeons who are called to active duty from civilian life have had little trauma experience and are asked to provide the initial surgical care of severely injured patients, they encounter problems inherent in the military trauma system. The patient may quickly leave the initial surgeon's care and subsequently move rapidly from surgeon to surgeon as he is swiftly transferred from hospital to hospital in the hierarchical Army trauma system. Such discontinuity of care increases the risk of sepsis as a consequence of delayed recognition of mechanical complications or other problems related to the initial operation.

In WWII, Dr. Tracy Mallory had noted that, in almost one fifth (18.6%) of casualties who died, there was histologic evidence of renal failure consistent with inadequate resuscitation.<sup>56</sup> In the Korean Conflict (1950–1953), which followed shortly after WWII, an increased understanding of the pathophysiology of injury and shock and technological advances combined to further improve combat casualty care. In the early years of the Korean Conflict, before the magnitude and rapidity of blood loss in casualties were fully appreciated, evidence of renal failure was present in slightly more than one third (36%) of autopsied casualties. After 1952, the prompt infusion of adequate volumes of resuscitation fluid to injured patients reduced the occurrence of renal failure to 0.5% of autopsied casualties.<sup>57</sup> Other advances that benefitted the injured soldier in the Korean Conflict were the development of the forward care surgical facility, Mobile Army Surgical Hospital (MASH) (Fig. 3), the first use of helicopters to transport casualties, and the use of prophylactic hemodialysis to minimize or avoid the complications of uremia.<sup>57,58</sup> The existing mandate for amputation of a limb with arterial injury was repudiated and limbs were salvaged by direct vascular repair and arterial replacement pioneered by Frank

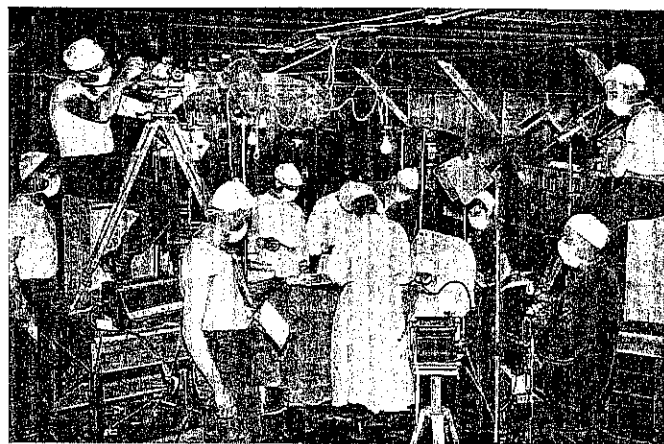
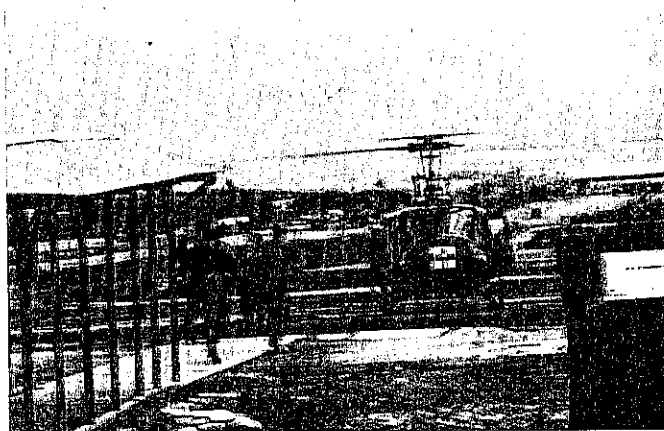


FIGURE 3. Prompt surgery at a forward-placed Mobile Army Surgical Hospital (MASH) as shown here reduced the injury to operation interval in the Korean Conflict and decreased the mortality associated with war wounds. Note photographers of the research team filming the operation. Courtesy of the National Museum of Health and Medicine, Washington, DC.

Spencer and Carl Hughes, both of this organization,<sup>59,60</sup> John Howard,<sup>61</sup> and John H. Davis.<sup>62</sup> The improvements in care of the wounded in the Korean Conflict were reflected in the further reduction of the mortality associated with abdominal wounds to 8.85%.<sup>63</sup>

The Army tradition of integrated research was extended to Korea by the activities of the Surgical Research Team organized by Col. William S. Stone, Commandant of the Army Medical Service Graduate School.<sup>62</sup> That team was led by Dr. John Howard and included Curtis Artz and John H. Davis. During its 20-month existence, the team described high output renal failure, identified seasonal variations in the predominant organisms causing infection in casualties, described changes in the coagulation system with injury and resuscitation, studied glucose metabolism and adrenal function in casualties, described the hepatic response to resuscitation in the wounded, and extended the studies of the physiologic response to injury beyond those conducted by the Board for the Study of the Severely Wounded.<sup>57</sup> The research findings were promptly applied to improve care and increase the salvage of casualties.

Additional improvement in the care of combat casualties was evident in the Vietnam Conflict. An abundant supply of certified surgical specialists permitted full staffing of sufficient definitive treatment facilities to reduce the time required for transportation of casualties to a hospital to unprecedented brevity. The proximity of treatment facilities to the sites of injury and the routine use of helicopters for patient transport resulted in the admission and treatment of patients who in previous conflicts would have never reached the hospital and further reduction of the injury to admission interval (Fig. 4). The care provided those patients was state-of-the-art in terms of mechanical ventilation, physiologic monitoring, and fluid resuscitation and achieved further reduction in mortality of casualties with penetrating wounds



**FIGURE 4.** In the Vietnam Conflict, "Dust-off" helicopters were dedicated for casualty transport. Prompt delivery of casualties to a MASH hospital or as shown here to an evacuation hospital, often within minutes of injury resulted in the salvage of patients with injuries previously associated with prehospital mortality.

and visceral injuries. Surgeons in Vietnam identified ARDS (Da Nang Lung) as a complication of severe injury and raised concern over its relationship to excessive fluid resuscitation,<sup>64</sup> an echo of the speculation voiced by the Board for the Study of the Severely Wounded 25 years earlier and a confirmation of Dr. Brewer's report of the "Wet Lung in War Casualties." Dr. Norman Rich, who promoted venous repair to reduce edema and increase salvage of badly injured legs, also initiated the Vietnam Vascular Registry, which is still being used to record and analyze outcomes in patients with vascular injuries.<sup>65</sup> Topical antimicrobial chemotherapy for the care of burns and other wounds was for the first time available in the theater of operations. Additionally, the Army Burn Center and the U.S. Air Force collaborated to develop a system of staged intercontinental transfer of severely burned patients, which reduced in-transit mortality to the vanishing point. The mortality of 23,396 wounded casualties admitted to U.S. Army hospitals in Vietnam during a 2-year period was reported as only 2.3% and the mortality of patients with abdominal wounds as 9.0%.<sup>63</sup> Both of those mortality rates were little changed from those of the Korean Conflict but markedly decreased from those of WWII and earlier wars (Table 1).

In the Vietnam Conflict, the U.S. Army Medical Corps' tradition of integrated clinical and laboratory research was maintained by the Trauma Study Section of the U.S. Army Medical Research Team in Vietnam. The surgeons assigned to that team described changes in the volume and composition of gastric secretions in casualties, measured the effect of injury on circulating levels of hepatic enzymes, and as their predecessor units had done, studied the hemodynamic and pulmonary changes in casualties.<sup>57</sup>

In the Granada, Panama, and Operation Desert Shield/Storm Conflicts since that time, research opportunities have been missed because there have been no dedicated surgical research units, sections, or teams sent to the theater of

operations. For Operation Desert Shield/Desert Storm, the Institute of Surgical Research provided teams of burn specialists to establish burn center capabilities at selected evacuation hospitals and provide theater-wide coverage for burn care in Saudi Arabia. The Institute also worked with the U.S. Air Force to reactivate the system of intercontinental aeromedical transfer that had worked so well for patients burned in Vietnam. That system was activated once again in 2003 for combat casualties burned in Iraq.

The slow and sometimes tortured progress in the care of patients with soft tissue wounds that has occurred since the time of Galen illustrates the many impediments to surgical progress in general. The tyranny of surgical dogma exemplified by the dicta of Hippocrates and Galen, and the tenacious theories of laudable pus and gunpowder poisoning, slowed surgical progress for centuries, if not millennia (Table 2). Ecclesiastic edicts forbidding surgery and ignorance of the pathogenesis and natural history of disease further impeded surgical progress. Limited clinical experience and lack of surgical qualifications also restricted progress in wound care, as did the artificial differentiation of military from civilian wounds debunked by John Hunter in the last decade of the 18th Century but strangely persistent in some quarters even today. The inhibiting effect of poor sanitation was confirmed by the staggering toll of disease in the Spanish-American War and by the reduction in disease and wound infections brought about by enforced hygienic measures in the Crimean War and our Civil War. Lastly, eclectic trauma care systems including variable facilities and undependable transportation maintained high casualty fatality rates until the development of regionalized hierarchical trauma care systems. The appearance of the motorized ambulance in WWII and the helicopter in the Korean Conflict also improved care by reducing the interval between injury and treatment (Table 1).

One can also identify essentials that have accelerated progress in the care of wounded patients. The factors that have fostered improvements in wound care include the high patient density and concentrated surgical experience in time of war. The availability of surgical expertise ensured by specialty education and certification and the rapid infusion of newly developed surgical procedures and specialized knowledge by members of the civilian surgical community serving

**TABLE 2.** Factors Influencing Progress in Combat Casualty Care

I. Impediments
A. Tyranny of surgical dogma
B. Ecclesiastic dicta
C. Lack of knowledge and qualifications
D. Lack of sanitation and impact of comorbid conditions
E. Absence of effective reliable trauma care system
II. Accelerators
A. Expansion of knowledge base
B. Prompt application of new technology
C. Availability of residency trained board certified surgeons
D. State of the art logistical capability
E. Integrated clinical/laboratory research program

during times of conflict have further advanced combat casualty care. In turn, that population of citizen soldiers who are surgeons disseminates the new developments in combat surgery into civilian practice when they return to their community. The prompt application of basic science developments, acceptance of new technology, promotion of sanitation to control comorbid factors, and the development of regionalized hierarchal trauma care systems have all contributed to the surgical progress that has improved casualty care. Modern logistical capability now makes it possible to implant components of that system virtually anywhere and bring the benefits of state-of-the-art care to casualties in the harshest environments.

In this review, I have heretofore largely ignored the problem of burn injury in warfare, but it was brought to the forefront of Army Medical Corps planning at the end of WWII. The atomic detonation at Hiroshima in 1945 instantaneously generated 59,500 burn casualties. That massive number and a comparable number of burns at Nagasaki alerted the Army to burn injury as a major problem in future conflicts. The incidence of burn injury in armed conflicts since that time has varied between 2% and 18% in conventional warfare, depending largely upon the tactical situation.<sup>66</sup> The threat of prodigious numbers of burns in future conflicts refocused the Army's Surgical Research Unit on the problem of burn injury at the midpoint of the 20th Century.

The outlook for severely burned patients at the time of WWII had improved from that in the days of Paré but was still bleak. Acute renal failure as a consequence of burn shock was so common that when the Surgical Research Unit (renamed the U.S. Army Institute of Surgical Research in 1970) moved to San Antonio in 1947 the burn center was equipped to perform hemodialysis. If resuscitation was successful, the burn patient was at risk for bleeding and perforation from stress ulcers of the upper gastrointestinal tract, respiratory failure as a consequence of inhalation injury, development of invasive burn wound sepsis in an indolent wound, and the autocannibalism of postburn hypermetabolism.

The first of those problems, postburn shock, had been partially addressed at the start of WWII when a National Research Council committee chaired by Isadore Ravdin arrived at a consensus resuscitation formula for military burn patients in which the recommended volumes were based on laboratory studies conducted by Henry Harkins.<sup>45</sup> Advances in burn patient resuscitation resulting from integrated research have essentially eliminated burn shock and early postburn renal failure, which has occurred in only 10 of 3266 recently treated burn patients at the Army Burn Center. Institute alumni who are or were members of the Southern Surgical Association who contributed to the improvements in burn patient resuscitation include Curtis P. Artz, John Moncrief, and Charles Baxter.<sup>67-69</sup> The risk of stress ulcer complications has also been largely eliminated by therapeutic application of the findings of integrated clinical and laboratory studies. The effectiveness of antacid prophylaxis is now well documented and has reduced the need for operative intervention from an average of more than 3 times per year to only once in the past 10 years. Members of the Southern

Surgical Association who contributed to those advances include James O'Neill, Joseph McIlhany, Kenneth Sirinek, and William Cioffi.<sup>70-73</sup>

When burn shock and renal failure were eliminated as complications of burn injury, the importance of inhalation injury as a comorbid factor became evident. Once again laboratory and clinical studies identified reliable accurate diagnostic modalities and led to improved treatment that has tamed inhalation injury. The effectiveness of prophylactic lung protective mechanical ventilation in patients with inhalation injury was first described at the meeting of this organization in 1990 by William Cioffi and Loring Rue.<sup>74</sup> Other members of the Southern Surgical Association involved in studies of inhalation injury were Frank DiVincenti and Joseph Moylan.<sup>75,76</sup>

A revolution in burn wound care has been brought about by effective topical antimicrobial chemotherapy, early burn wound excision, and the development and use of effective skin substitutes. Those advances have reduced the incidence of invasive burn wound infections to only 2.3% of admissions and decreased burn patient mortality due to invasive infection by a factor of 20. Members of the Southern Surgical Association who contributed to those advances include Curtis Artz, John Moncrief, Robert Hummel, Alvin Bronwell, Wesley Alexander, James O'Neill, Jerry Shuck, P. William Curreri, Andrew Munster, David Herndon, and David Mozingo.<sup>77-84</sup>

Lastly, John Duckett, Jr, P. William Curreri, Joseph Moylan, Wesley Alexander, and David Herndon, all members of the Southern Surgical Association, and other investigators conducted studies that described and quantified postburn hypermetabolism and defined the components of modern day metabolic support.<sup>85-89</sup> The metabolic support regimens based on those studies are now applied to a wide variety of critically ill and severely injured patients to preserve lean body mass and accelerate convalescence.

The improvements in burn patient care which have occurred in the past half-century have increased survival to truly impressive levels. Particularly important to the military has been the reduced mortality in the 15- to 40-year age group encompassing active duty soldiers in which the LA<sub>50</sub> (the extent of burn fatal to 50% of patients with that extent of burn), formerly only 43% of the body surface, has increased to 75% of the body surface (Table 3). Of the 368 casualties burned in the current conflict in Iraq and transferred to the Army Burn Center, only 12, or 3.3%, have died. The magnitude of that improvement and the velocity with which it has occurred document the effectiveness of integrated clinical/

TABLE 3. Improvement in Survival of Military-Age Burn Patients: U.S. Army Institute of Surgical Research (1945-2002)

Age Group	LA <sub>50</sub>			
	1945-1957	1979-1983	1987-1991	1992-2002
Young adult (15-40 years)	43%	61%	82%* 72%†	75%* 65%†

\*21 years.

†40 years.

laboratory research. In that research format, experienced surgical scientists working at centers of excellence where patients of interest are concentrated can identify problems of clinical importance, which are then taken to the laboratory. There highly qualified investigators can develop a model for use in identifying effective interventions. Those candidate treatments are then returned to the bedside for clinical confirmation of effectiveness and identification of limitations or complications. The key to the success of such a synergistic reiterative bedside to bench to bedside research program is continuity of both institution and staff, which has distinguished the Army's program of burn research at the Institute of Surgical Research from that in nonburn trauma, in which the research organizations have been generally short-lived and staffed by individuals on short-term assignment.

Unfortunately, the absence of even short-lived in-theater research units in all conflicts since Vietnam means that important research opportunities have gone and are going unrealized. Colonel John Holcomb and staff members of the reorganized U.S. Army Institute of Surgical Research are supervising individual research projects focused on field first-aid, resuscitation fluids, and coagulation agents. Perhaps those studies can be expanded and provide the rationale for the establishment of on-site research teams or units to restore the Army Medical Corps' tradition of integrated casualty care research within the theater of operations.

Although the wounding capacity of modern weaponry has increased exponentially since the time of the American Revolution, unprecedented salvage of the severely injured and the extensively burned is being realized. In the Vietnam Conflict, there were a total of 58,203 deaths (0.7%) among the total 8,744,000 who served as compared with the 4435 deaths (1.8%) among the maximum estimate of 250,000 who served in the Revolutionary War, in which muskets and cannon balls were the weapons of the day (Table 1). The military surgeons of today are providing combat casualty care based on experience in previous wars and the information generated by integrated research during and between conflicts. Continuation of such research in combat casualty care will ensure ongoing surgical progress and further improvement in the outcomes of both military and civilian casualties.

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